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Application of LoRa Technology in Monitoring Solution for Photovoltaic Systems

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Abstract

Solar array systems with photovoltaic (PV) modules are extensively utilized in remote fields, agriculture, military, and various other sections. However, the challenge lies in the long distances between these installations and end-users, necessitating remote monitoring systems. In this study, we leverage Long Range (LoRa) wireless communication technology due to its extended range, cost-effectiveness, and user-friendly nature. The study focuses on the design and implementation of a Monitoring System (MS) tailored for PV applications, utilizing LoRa technology. The primary objective is to enhance the efficiency, reliability, and maintenance of PV installations by continuously monitoring system health and performance. The MS encompasses sensors, microcontrollers, and processors to collect and process data on PV, battery banks, load, and grid parameters, including voltage, current, temperature, and state of charge (SoC). Processed data is transmitted via LoRa to a centralized control station for analysis and decision-making. LoRa's attributes, such as long-range coverage, low power consumption, and obstacle penetration, make it particularly suitable for remote PV installations. We provide a detailed overview of the system architecture, components, communication protocols, as well as data processing algorithms and battery health estimation techniques. Experimental evaluation conducted on a test PV setup demonstrates the MS's effectiveness in monitoring battery health, anomaly detection, and facilitating remote maintenance in the normal and up-normal conditions and modes. Simulation on the MATLAB/Simulink platform validates the system's functionality under various operating conditions, ensuring robust performance.

Keywords: Renewable Energy, Solar Array, PV, Monitoring System, Lora, Battery, Operating Conditions and Modes.

1. Introduction

The Internet of Things (IoT) denotes a system where physical devices, appliances, vehicles, and other objects are interconnected through sensors, software, and internet connectivity. This network enables the collection and exchange of data over the internet, allowing for remote monitoring and control. IoT enables seamless integration between the physical world and computer systems, facilitating data gathering, analysis, and automation to improve efficiency and decision-making processes, ultimately enhancing quality of life. IoT signifies a significant advancement in comparison to the existing Internet infrastructure[1], [2], [3]. The primary objective of the IoT is to enhance operational efficiency and facilitate adaptation. The spread of smart objects and devices within the IoT has experienced a substantial growth. This phenomenon facilitates the manifestation of intelligent behavior in a diverse range of devices. IoT-enabled items have been equipped with intelligent functionalities, including sensors, RFID technology, and other forms of embedded computing. The notion of a globally networked future is no longer confined to futuristic technology significant of science fiction. The various devices and objects in our surroundings are interconnected inside a network commonly referred to as the IoT[4], [5].

Consequently, a universally accepted definition of the IoT is lacking, leading to a lack of clarity regarding its implications. Numerous acronyms and abbreviations have been devised to denote the concept of the IoT,

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including M2M (Machine to Machine), WoT (Web of Things), CoT (Cloud of Things), and IoE (Internet of Everything). While there are writers who contend that the two expressions possess identical meanings, there are others that establish evident differentiations between them. The IoT is a complex network that has the potential to introduce numerous innovative concepts and societal conventions[6], [7], [8], [9]. The primary objective of IoT innovations is to streamline operations across diverse sectors, enhancing system efficacy, and ultimately elevating the overall quality of life. This ambitious goal encompasses a multitude of applications, permeating virtually every facet of modern existence[10], [11].

Similarly, the incorporation of IoT technologies into industrial processes reshapes manufacturing paradigms, fostering enhanced production processes and seamless communication between human operators and machinery[12]. This comprehensive monitoring extends across the production chain, from quality control to logistics and distribution, ensuring operational efficiency and minimizing losses to bolster market competitiveness. In a groundbreaking advancement, a Monitoring System (MS) that leverages LoRa and IoT technologies in rural areas underscores the transformative potential of wireless sensor networks (WSNs)[9]. LoRa, short for Long Range, is a Low-Power Wide-Area Network (LPWAN) protocol that enables long-distance communication between devices with minimal energy consumption. It operates on unlicensed frequency bands, making it suitable for applications in remote and rural areas. LoRa technology is closely intertwined with the IoT, a network of interconnected devices capable of exchanging data over the internet. In the context of the MS mentioned, IoT facilitates the collection, transmission, and analysis of data from sensors deployed in rural environments[13]. By integrating LoRa with IoT, the MS enables efficient and cost-effective monitoring of various parameters, such as environmental conditions or photovoltaic system performance, over large geographical areas[14].

Despite challenges like node vulnerability to damage and extreme weather events in photovoltaic systems, innovative solutions such as subterranean sensor networks ensure continuous real-time data acquisition. These networks, enabled by LoRa and IoT technologies, enhance the resilience and reliability of monitoring systems in remote locations. Moreover, wireless sensor networks (WSNs) equipped with LoRa technology have become indispensable across diverse sectors, including industry, healthcare, and precision agriculture. They offer versatile monitoring capabilities, allowing for the collection of data in various environmental conditions. LoRa technology is suitable for a wide range of applications, including smart cities, agriculture, and industrial monitoring[15], [16]. This underscores the significance of LoRa-enabled IoT solutions in addressing monitoring and communication challenges across different domains. Additionally, the segment evaluates communication protocols to tackle challenges in contemporary IoT platforms serving photovoltaic batteries[17]. This highlights the importance of selecting appropriate communication protocols, such as LoRa, to optimize data transmission and enhance the efficiency of IoT-enabled monitoring systems in specific applications like photovoltaic systems. In order to furnish a thorough comparison of different LPWAN technologies, encompassing LoRa, Sigfox, NB-IoT, and Zigbee, all of which emerge as potential contenders for expansive IoT implementations[18], the authors precisely analyze the technical attributes of these technologies and evaluate their applicability across diverse IoT scenarios.

In the study, the authors use LoRa technology to design and implement a battery monitoring system for PV applications. LoRa technology was first and has since gained popularity due to its ability to provide long-range communication at a low power consumption. In a paper[19], the authors discuss the advantages of LoRa technology, including its long-range communication capability (up to 10 km in rural areas), low power consumption (up to 10 years' battery life), and high interference immunity.

Several studies have proposed the use of LoRa technology for monitoring systems (MS) in PV applications. Peruzzi and Pozzebon studied a monitoring system based on LoRa technology, designed and implemented for a 24V battery bank in a PV system. The MS was able to monitor the voltage, current, and temperature of the battery bank and transmit the data wirelessly to a remote monitoring station over a distance of 3 km. The system was also able to send alerts to the monitoring station in case of battery overcharge or discharge[19].

In another study, Gupta and Gupta proposed a MS based on LoRa technology for a 12V battery bank in a PV system. The BMS was able to monitor the SoC, SoH, and SoF of the battery bank and transmit the data wirelessly to a remote monitoring station over a distance of 2 km. The system was also able to send alerts to the monitoring station in case of battery overcharge or discharge[20].
Cabello et al., designed a battery monitoring system (BMS) based on LoRa technology and implemented for a 48V battery bank in a PV system. The BMS was able to monitor the voltage, current, temperature, and SoC of the battery bank and transmit the data wirelessly to a remote monitoring station over a distance of 1 km. The system was also able to send alerts to the monitoring station in case of battery overcharge or discharge[21].
Talib et al., focuses on developing a PV monitoring system that can help ensure the efficient operation of photovoltaic (PV) systems. The study begins by highlighting the importance of battery monitoring in PV

systems, particularly in remote areas where power supply is unreliable[22].

Raza et al., emphasize that a reliable battery monitoring system can help prevent downtime, reduce maintenance costs, and prolong the lifespan of the batteries. They argue that a low-power, wide-area network (LPWAN) technology like LoRa can be used to design a cost-effective and efficient battery monitoring system[23].

Khalifeh et al., designed a system consisting of a microcontroller unit (MCU), a LoRa module, a battery voltage and current sensor, and a temperature sensor. The MCU is responsible for collecting data from the sensors and transmitting it wirelessly to a base station via LoRa technology. The authors explain that LoRa technology is particularly suitable for battery monitoring systems because it provides a long-range communication capability, low power consumption, and high interference immunity [24].

Kutluay et al., present the results of their experiments to evaluate the performance of the proposed system. They conducted tests on a 12 V lead-acid battery that was charged and discharged at different rates. The results showed that the battery monitoring system was able to accurately measure the battery voltage, current, and temperature, and transmit the data wirelessly to the base station. The authors also noted that the system had a low power consumption and could operate for a long time on a single battery[25].

Despite its advantages, LoRa technology also has some limitations. In a study Raza et al., identify several limitations of LoRa technology, including its limited data rate (up to 50 kbps), susceptibility to interference from other LoRa networks, and the need for a clear line-of-sight for long-range communication. The authors suggest that LoRa technology may not be suitable for applications that require high data rates or are located in areas with high levels of interference[23].

Traditional wireless communication technologies used in battery monitoring systems, such as Wi-Fi and Bluetooth, may not provide sufficient coverage in remote areas or may consume excessive power, leading to inefficiencies and increased maintenance costs. The implementation of a battery monitoring system for photovoltaic applications based on LoRa technology can potentially overcome these challenges. LoRa offers long-range and low-power capabilities that are well-suited for monitoring and managing battery systems in remote and off-grid locations. The key problem to address is how to design and implement a reliable, energy-efficient, and scalable battery monitoring system using LoRa technology, which can cater to different battery types and photovoltaic system setups while ensuring data security and real-time monitoring and control.

In this study a LoRa Based battery monitoring system for PV applications has been designed and simulated by MATLAB/Simulink. The study shows that instead of other wireless connections such as Wifi and Bluetooth, LoRa can also be used for monitoring battery. Different from other studies, this study investigates the LoRa for longer distance of 5 km. Also the design of the PV system is wider and more comprehensive. Moreover, maximum power point tracking (MPPT) and voltage control modes are applied.

2. Materials and Methods

The suggested system consists of two components, of which the first is the PV solar system comprising a solar cell arrays, MPPT, boost converter, battery bank, bidirectional converter, load, and controller. The study comprises the LoRa communication and monitoring MATLAB simulation which are employed for transmitting and receiving significant system parameters, like voltages, current, power, and some other parameters.

2.1. PV System

Figure 1 depicts the PV system with monitoring system, which consists of boost controller, the PV array, MPPT controller and the load.

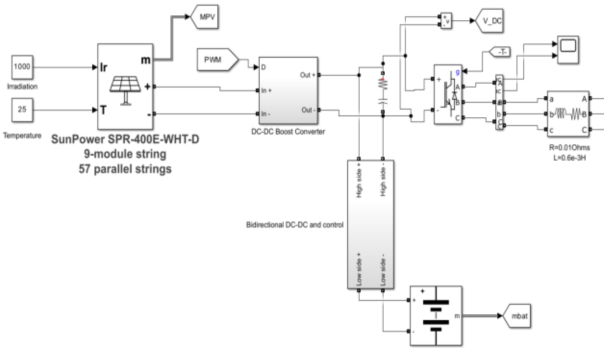

Figure 1. PV system

The proposed system outlines the configuration of complete grid connected photovoltaic three-phase AC power system with battery backup, facilitating the following objectives:
- Determine the required battery ranking depended on the connected load profile and the obtainable solar energy.
- Establish the optimal arrangement of panels, considering the number of connected series and parallel strings panels.
- Design a constant voltage three-phase AC supply.
- Choose appropriate values for the proportional gain and of the PI controller and the phase-lead time constant.

Both the solar PV and battery storage components are capable of supporting grid-connected three-phase loads, with the load connected to a constant voltage three-phase AC supply. The solar PV system operates in two modes:

maximum power point tracking (MPPT) and de-rated voltage control modes, employing a battery management system equipped with bi-directional DC-DC converters.
For MPPT of the solar PV system, the system utilizes the Perturbation and Observation (P&O) technique as one of the available MPPT techniques.
Various parameters can be specified within the system, including the average daily connected load profile, the daily available average solar energy in the region (measured in kWh), operating temperature of the solar PV system, day of autonomy, battery recharge time, output DC voltage, and specifications of the solar panels used. The determination of the number of PV panels required to meet the specified generation capability relies on data provided by the manufacturer of the solar panels. PI controller of the form is chosen to control the solar PV and battery management system.

2.2. LoRa Model

A MATLAB file code used to simulate LoRa transceiver to calculate BER and required transmission power and SNR. LoRa simulation based on the MATLAB code published by [26]. The published code is used to simulate LoRa communication system for "Multiple-Frequency-Shift-Keying (MFSK)" modulation in both coherent and none-coherent techniques, and also the system simulated for two types of noise.

The solar plant voltage, current, irradiance and power are transmitted over LoRa communication system and monitored in the remote-control room. The proposed system simulated for all possible operating cases. The flow chart of the system is shown in figure 2.

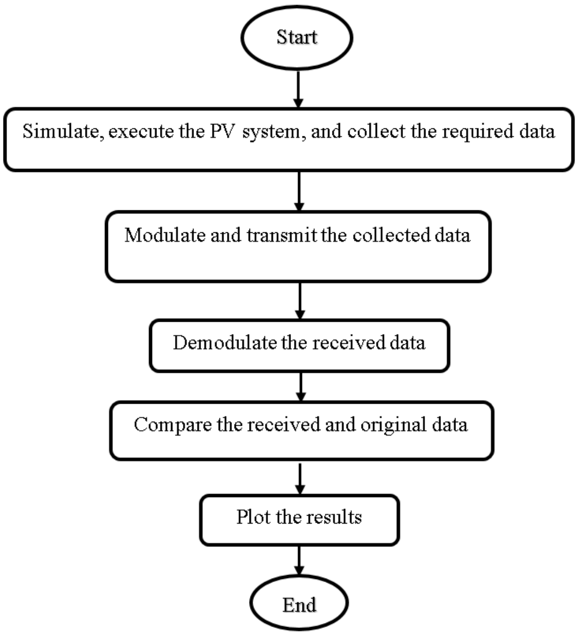

Figure 2. Flowchart of the system

2.3. LoRa Protocols

In the context of a battery monitoring system, LoRa technology can be used to implement the Medium Access Layer (MAC) protocol for wireless communication. The MAC layer is responsible for managing the transmission of data between devices in a network, and Lora technology provides a reliable and efficient method for wireless communication between battery monitoring devices. In the context of a battery monitoring system using Lora technology, the MAC layer can be implemented using the following steps:

•Establishing a Network: The first step in implementing the MAC layer is to establish a network. This involves setting up a Lora gateway, which serves as the central communication hub for the battery monitoring devices. The gateway is responsible for receiving data from the battery monitoring devices and forwarding it to the appropriate destination.

•Defining Communication Channels: Once the network is established, communication channels need to be defined. Lora technology uses a spread spectrum modulation technique to transmit data over multiple frequency channels. By defining communication channels, the battery monitoring devices can communicate with the gateway without interfering with each other.

•Implementing the MAC Protocol: With the network and communication channels defined, the MAC protocol can be implemented. The MAC protocol manages the transmission of data between the battery monitoring devices and the gateway. It defines the rules for accessing the communication channels, handling collisions, and ensuring reliable communication.

•Transmitting and Receiving Data: Once the MAC protocol is implemented, data can be transmitted and received between the battery monitoring devices and the gateway. The battery monitoring devices collect data on the battery voltage, current, and temperature, and transmit it wirelessly to the gateway using LoRa technology. The gateway receives the data and forwards it to a central database or user interface for analysis.

Figure 3 illustrates a simplified LoRa frame, featuring the addition of a LoRa protocol header. This LoRa header is crucial for transmission and consequently prolongs the transmission time, despite the number of useful bits remaining unchanged. As a result, the effective transmission throughput is reduced.

Figure 3. LoRa technology MAC frame

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In the context of utilizing the LoRa protocol, various protocol layers have been introduced. Each layer provides specific services, with the upper layers being closer to the user, while the lower layers pertain to the transmission medium. As illustrated in Figure 4, the LoRaWAN protocol consists of two main layers: the application layer and the Medium Access Control (MAC) layer. These layers form the basis of the LoRaWAN protocol, which facilitates transmission over the internet via gateways. As the frame passes through the gateway, a different header is appended to the frame to enable transmission over the internet. This new header, known as the IP header, allows the frame to be transmitted over the internet while preserving the content of the original LoRaWAN frame. Thus, the content of the LoRaWAN frame remains intact throughout the transmission process.

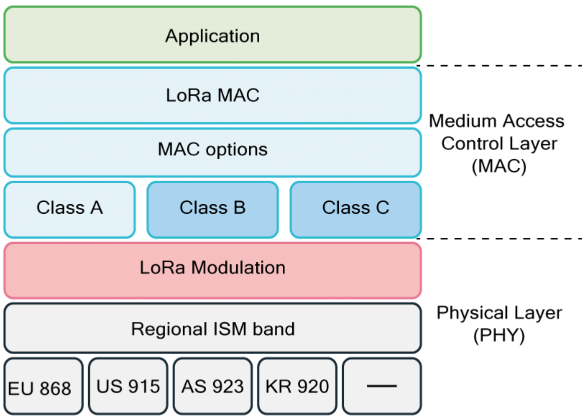

Figure 4. LoRa MAC protocol layers for the design of EMS[27]

In the utilization of the LoRa protocol, additional protocol layers have been incorporated, with each layer providing specific services. As the data is transmitted through the frame, it undergoes encapsulation in each lower layer, effectively adding details to the transmission process. The composition of the entire LoRa frame, including the information encapsulated at each layer, is illustrated in Figure 5, where the LoRa spreading frame is as depicted in Figure 6.

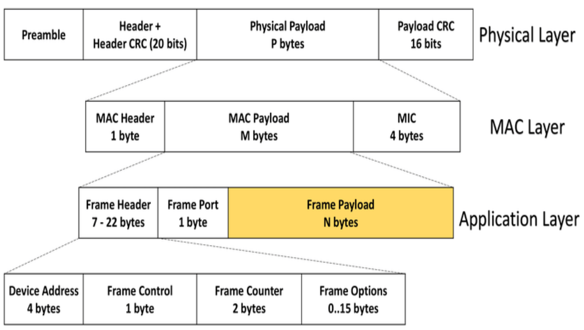

Figure 5. Frame of the LoRa different layers[28]

Before encapsulating user data in the Application layer, they undergo encryption using the Application Session Key (AppSKey) to ensure the security of the transaction.

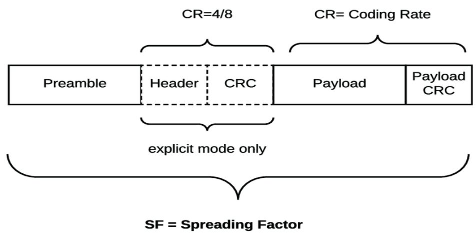

Figure 6. Spreading factor LoRa frame for EMS PV application[28]

3. Discussion

3.1. LoRa Simulation

In this work the communication system simulated in specific conditions to check its performance. In LoRa technology a distance of 5km has been considered. Voltage, current, SoC, load and power has been examined.

Figure 7 shows the BER for coherent and non-coherent FSK modulation and noises with respect to the SNR, the simulation outcomes compared for AWGN noise.

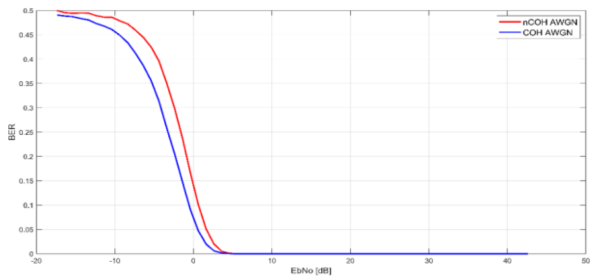

Figure 7. BER for LoRa in coherent and non-coherent FSK for AWGN noise effect

While the system response in case of Rayleigh noise is shown in figure 8.

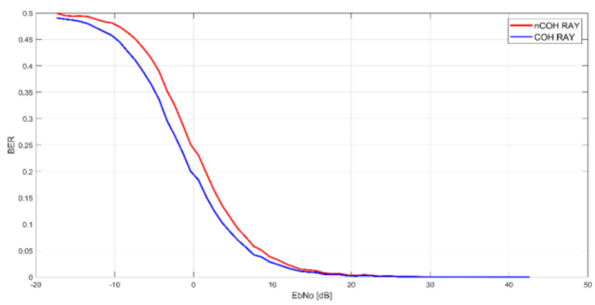

Figure 8. BER for LoRa in coherent and non-coherent FSK for Rayleigh noise effect

The power/frequency curve is shown in figure 9.

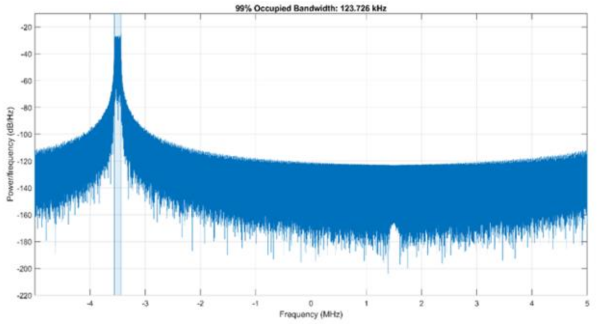

Figure 9. Occupied bandwidth

While figure 10 is showing the spectrum density for the LoRa communication system

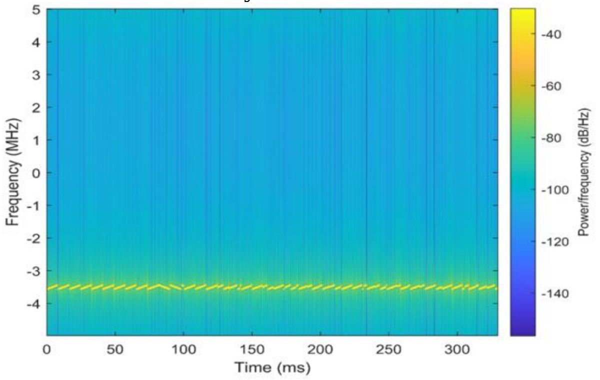

Figure 10. Spectrogram for LoRa communication system

3.2. PV System

The PV solar system is simulated for all expected operating conditions (solar irradiance level, loading, MMPT, Constant voltage). The following sets are used and the results are generated by using the values in Table 1.

Table 1. Parameters of the system used in the simulation

Parameters	**Value**
Required PV Power rating	200 kW
Minimum number of panels required per string	8 pcs
Maximum number of panels connected per string without reaching maximum voltage	10 pcs
Minimum power rating of the solar PV plant	1,80 kW
Maximum power possible per string without reaching maximum DC voltage	400 W
Actual number of panels per string	9 pcs
Number of strings connected in parallel	57 pcs
Actual solar PV plant power	200 kW
Rated Ah of the battery	400 Ah
Battery nominal voltage	400 V
Fully charged voltage	465 V
Reference battery charging current	45,24 A
Nominal (Average) discharge current	43,48 A
Maximum battery discharging current	43,47 A
Initial state-of-charge (%)	70%
Maximum battery charging Power	~18 kW
Maximum battery discharging Power	~16 kW

The battery discharge parameters can be concluded with the figure 11.

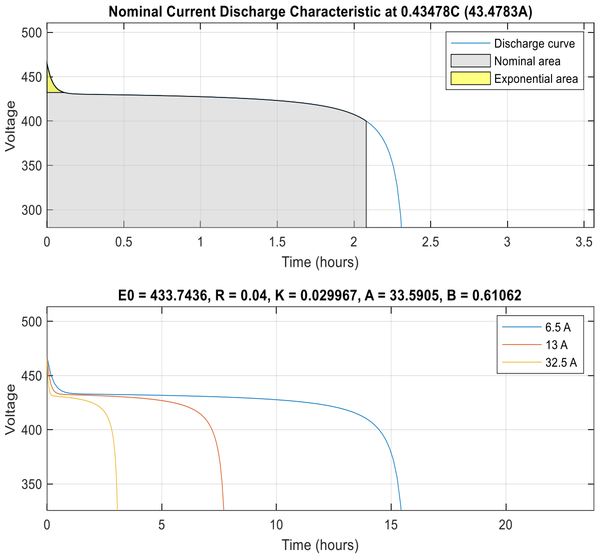

Figure 11. Battery discharging parameters (voltage, current, time)

To understand the system behavior with the monitoring, it can take the normal operating case with irradiance of G=1000W/m^2 and STC temperature with T=25C°. The PV voltage (V_{PV}), current (I_{PV}), and the power (P_{PV}) are shown in the figure 12.

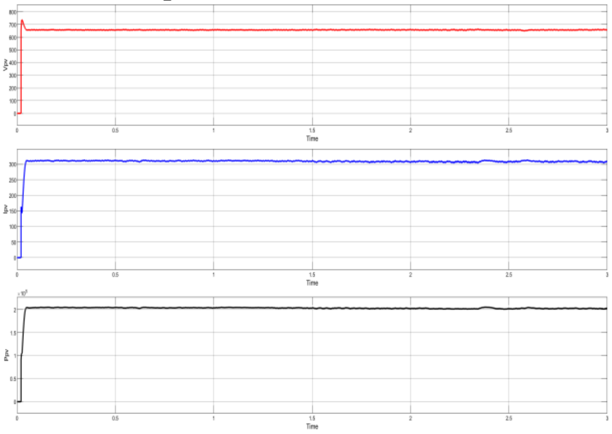

Figure 12. PV voltage, current, and power under a 1000W/m^2 results

As the irradiance is constant along the whole period, so the PV voltage, current, and power are of fixed values that are related to our system configuration. Also for continuous controlling the system, it is clear from figure 13 that the real power (P) is varied according to the control state and the reactive power (Q) is always zero to keep the unity power factor for the PV system.

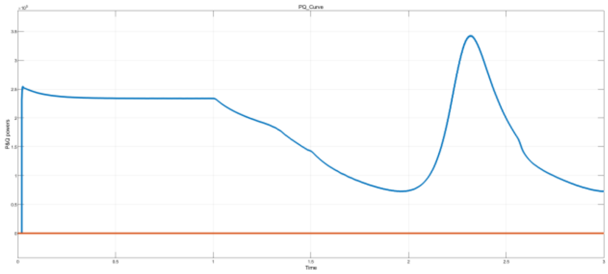

Figure 13. The real power (P) and the reactive power (Q) for the PV part

As illustrated in figure 14, the three phases voltage (V_{abc}) and current (I_{abc}) that are supplied to the P_{CC} and hence to the load or the grid are pure sine waves and with appropriate values.

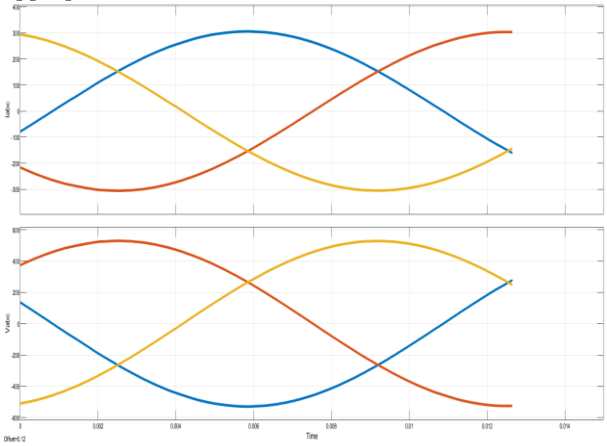

Figure 14. The three phases voltage (V_{abc}) and current (I_{abc})

The load types in the reality system are inductive load type, so there are generated real power (P_L) and reactive power (Q_L) that are both greater than zero. Figure 15 depicts the load powers.

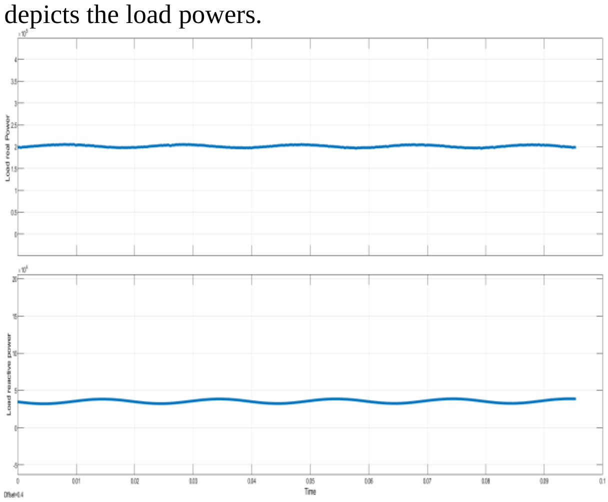

Figure 15. Real power (P_L) and reactive power (Q_L)

The load demand (P_L) is varied during the period, as a result the battery and grid powers (P_{bat} & P_G) are varied also depending on the load variation. Figure 16 explains the load variation effect on system performance.

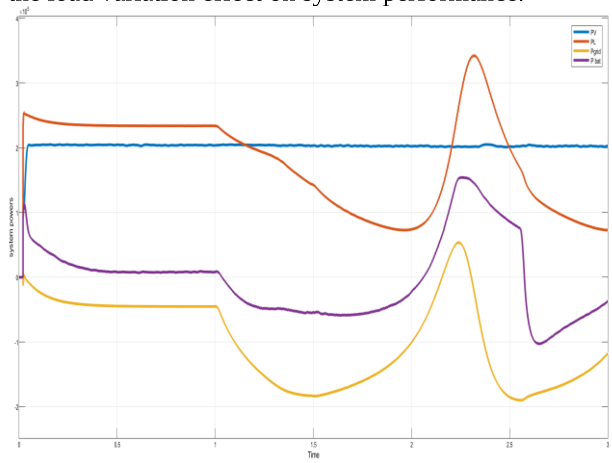

Figure 16. Load variation effect on system performance for 1000W/m^2

It can divide and test the validity of the proposed PV system during its operations periods as:
From (0-1) sec, the P_L is greater than P_{PV}, so the battery can compensate the difference and the P_G is near to zero.

From (1.1-2.2) sec, the P_L is lower than P_{PV}, so the battery can be in idle state and the difference between P_{PV} and P_L is transferred to the grid as a P_G.

From (2.2-2.5) sec, the P_L is overstated to high power value and the P_{PV} with the P_L can't provide the load demand requirement, as a result the grid power P_G can compensate the system by the required power.

From (2.5-3) sec, again the P_L is lower than P_{PV}, the battery is of good charging level, the difference between P_{PV} and P_L is transferred to the grid as a $P_{G.}$

The state of the battery operation under the case study is as shown in figure 17.

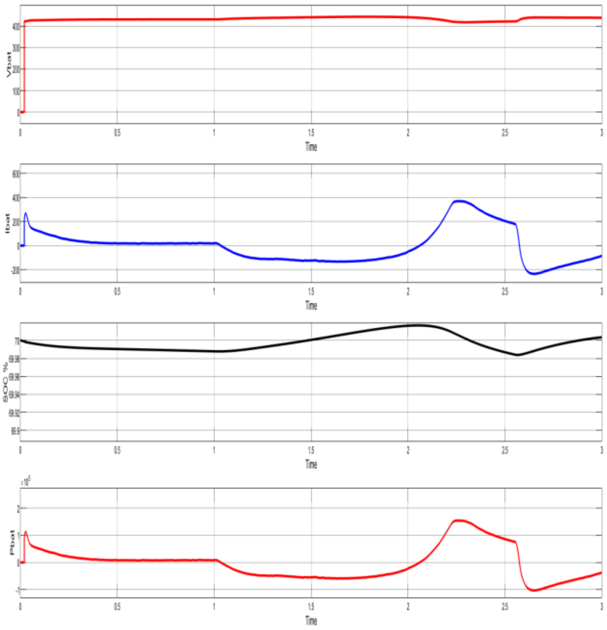

Figure 17. The battery voltage, current, SoC and power curves for 1000W/m^2

It is clear the battery state curves that the battery voltage V_{bat} can keep its value with constant along the whole period, while the battery current I_{bat} and power P_{bat} is varied depending to the system working and with three levels: high to charge the battery, low when discharging the battery, and constant when no needing to the battery power. The state of charge (SoC) is varied according to battery operating modes, however, in the case under study the SoC is near to nominal setting value which is 70%.

In our research, we aim to develop a comprehensive monitoring and data acquisition system for a photovoltaic (PV) solar power system integrated with battery storage, load, and grid connection. The primary objective is to ensure efficient operation and management of the system by continuously monitoring key parameters such as PV voltage, current, and power; battery voltage, current, power, and State of Charge (SoC); load voltage, current, and power; as well as grid voltage, current, and power.

In our operational modes and throughout the entire duration, we continuously monitor previous states and values by displaying results using MATLAB/Simulink interfaces. For each parameter, we transmit four values: the maximum (max.), minimum (min.), mean, and variance. The max. value signifies the highest recorded value, while the min. value indicates the lowest. The mean value represents the average, and the variance reflects the deviation from the mean, representing the standard deviation. These measurements are taken for significant parameters including:
- Photovoltaic (PV): Voltage (V_{PV}), current (I_{PV}), and power (P_{PV}).
- Battery: Voltage (V_{bat}), current (I_{bat}), power (P_{bat}), and State of Charge (SoC).
- Load: Voltage (V_L), current (I_L), and power (P_L).
- Grid: Voltage (V_G), current (I_G), and power (P_G).

Subsequently, LoRa technology is utilized to continuously transmit and receive the aforementioned values, saving them as a worksheet or Excel file for further analysis.

By continuously monitoring these parameters, we can assess the performance of each component within the system and identify any anomalies or deviations from expected values. This real-time monitoring capability enables us to optimize system operation, detect and diagnose faults or failures promptly, and make informed decisions regarding system maintenance and performance improvement.

Furthermore, by transmitting the monitored data using LoRa communication technology, we can remotely access and analyze the system's performance data in real-time. This remote monitoring capability is particularly valuable for off-grid or remote solar power installations, where on-site inspection and maintenance may be challenging or impractical.

Overall, our goal is to develop a robust and reliable monitoring system that provides valuable insights into the performance and operation of PV solar power systems, facilitating efficient management and optimization of renewable energy resources.
Now, if the radiation is 800 W/m^2 and STC temperature with T=25C°, the PV voltage (V_{PV}), current (I_{PV}), and the power (P_{PV}) are shown in the figure 18.

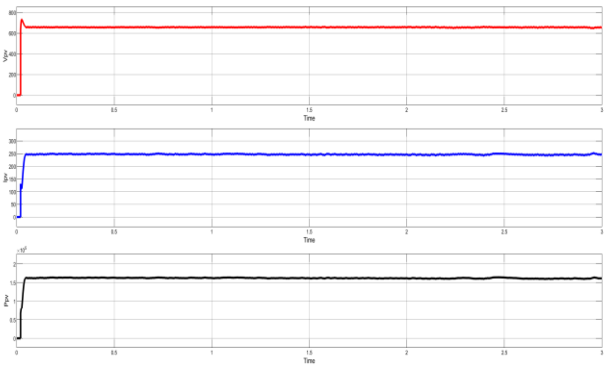

Figure 18. PV voltage, current, and power under 800W/m^2 results

Figure 19 explains the load variation effect on system performance.

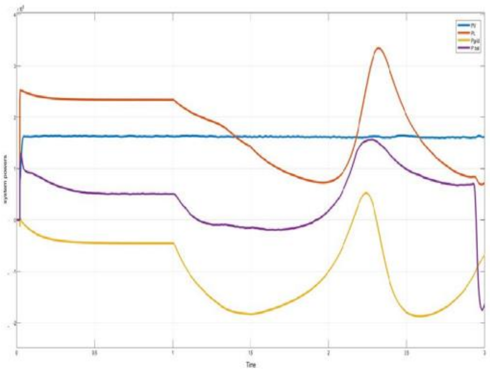

Figure 19. Load variation effect on system performance for 800W/m^2

The state of the battery operation under the case study is as shown in figure 20.

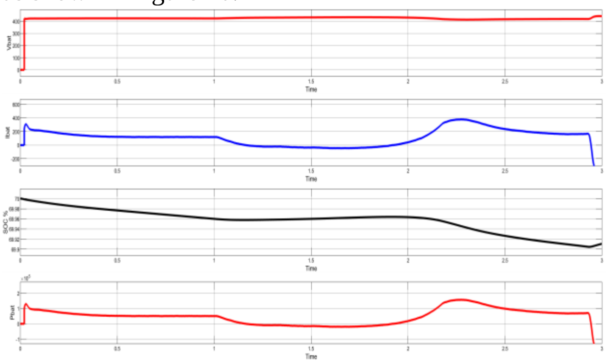

Figure 20. The battery voltage, current, SoC and power curves for 800W/m^2

4. Conclusion

PV solar array systems are widely used in many applications and always installed in far places, therefor such systems need remote monitoring process with suitable communication tool that can easily transceiver the commands and data. In this work, an IOT application for remote monitoring of grid-off /grid-connected solar PV array systems supplied with variable load is installed. The communication system used for data transmission is LoRa based. The solar power system works in two modes depending on the connected load, MPPT mode and constant voltage mode.

Data collection and processing play a critical role in monitoring systems tailored for Photovoltaic (PV) applications. It outlines the types of data collected by the system, encompassing various parameters such as PV performance metrics, battery status indicators, load characteristics, and grid-related parameters. To facilitate efficient transmission, this data will be transmitted using LoRa technology, ensuring secure communication channels while integrating robust security measures to safeguard the integrity of the transmitted data.

Solar power system simulated using MATLAB/Simulink software for all expected operating cases such as solar irradiance variation and load variation. LoRa communication system also simulated using MATLAB software for many types of modulation and SNR.

The system readings (voltages, currents, and powers) are transmitted and received in the remote monitoring room. The transmitted and received data are compared to show the system performance. For all simulated cases the data accuracy is very high.

The PV system operates in different modes, which are influenced by factors such as solar irradiance, generated solar power, connected load, battery state of charge (SoC), and maximum battery charging/discharging current limits. To optimize the system's performance and track the maximum power point (MPP) of the solar PV, two maximum power point tracking (MPPT) techniques can be employed: Incremental Conductance (INC) or Perturbation and Observation (P&O).

Several parameters need to be specified, including the average daily connected load profile, the region's daily available average solar energy (kWhr), solar PV system operating temperature, day of autonomy, battery recharge time, AC supply availability, and solar panel specifications. The determination of the number of PV panels required to meet the specified generation capability is based on data provided by the solar panel manufacturer.

Among numerous variables, the DC bus voltage level (Vdc), solar irradiance (G_{rad}), and battery state of charge (SoC) are crucial in determining the appropriate operating mode through supervisory control.

For future work, the studied system can be implemented using physical components that can verify the system performance from networking site of view. Also the examined system can be instantiated using real time components like microcontrollers, networking adaptor and attachable devices.Moreover, a double control room system may be a good solution for both communication loss or to overcome the local controller failure, to make the system more stable.

Lastly, in a viability of Wi-Fi system, it can depend on more accurate and friendly communication protocol like the ThinkSpeak environment protocol.

Author's Contributions

Ercan Aykut: Supervising, writing, editing, evaluating.

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Ethics

There are no ethical issues after the publication of this manuscript.

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